FOAM Coarsening

Experiment Scientific Requirements

Document reference	ESA-HME-ESR-FOAC-I1R0
Issue	1
Revision	0
Date of issue	
Status	Baseline
Document type	Requirements
Distribution	HME-G, HME-GA, HME-GO, HME-GP

Signatures page

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Change record

Issue	Date	Page	Change Description
1, rev. 00			Original document

List of acronyms

APD	Avalanche PhotoDiode
CAC	Critical Aggregate Concentration
CCD	Charge-Coupled Device
CCS	Camera Control Software
CMC	Critical Micellar Concentration
DTS	Diffuse-Transmission Spectroscopy
DWS	Diffusing-Wave Spectroscopy
EC	Experiment Container
EP	Experiment Procedure
ESA	European Space Agency
FOV	Field of View
fps	Frames Per Second
FSL	Fluid Science Laboratory
IR	Infrared
ISS	International Space Station
MAP	Microgravity Application Programme
MSG	Microgravity Science Glovebox
PIV	Particle Image Velocimetry
SVS	Speckle Variance Spectroscopy
TBC	To Be Confirmed
TBD	To Be Determined

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1 INTRODUCTION

"Administrative" details of the experiment.

- Project ID: AO 99-108
- Acronym: Coarsening FOAM

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2 GENERAL DESCRIPTION

Goal: provide information about the scientific questions at stake, the objectives of the experiment and previous experience if available.
Contents:

- *General scientific background and motivation*

Foams are dispersions of gas into liquid or solid matrices. They are made in conditions where the matrix is liquid (in solid foams, the matrix is solidified afterwards). The behaviour of foams in micro-gravity and on earth are very different, because the process of drainage is absent in micro-gravity conditions. By drainage, we are referring to the irreversible flow of liquid through the foam (leading to the accumulation of liquid at the foam bottom, and to a global liquid content decrease within the foam); in this case the bubbles deform to polyhedra throughout the upper portion of the foam, creating the so-called "dry foam". When the liquid films between the bubbles are very thin, they eventually break, and the foam collapses. This happens when suitable stabilizing agents are absent (well chosen surfactants or solid particles for aqueous foams). Micro-gravity offers the opportunity to investigate the so-called "wet" foams, which cannot be stabilized on earth because of drainage (drainage gets faster as the foams gets wetter). Theoretical approaches of drainage rely on assumptions, which are only valid for dry foams. New behaviours or regimes are expected to appear for wet foams, masked by convective instabilities on Earth. Elastic and viscous properties of wet foams will also be strongly modified by the presence of solid particles. The Physics of wet foams is therefore poorly known, and is one major goal of this project.

The FOAM project aims at the study of aqueous and non-aqueous foams in the micro-gravity environment on-board the International Space Station (ISS). The FOAM project is divided in two experiments: “FOAM coarsening”, topic of this ESR, and “FOAM stability”.
The objective of FOAM coarsening is the study of the quiescent coarsening of foams as a function of the liquid fraction. The project focuses on very wet foams which cannot be studied on ground, due to drainage effect. Conductimetry and multiple light scattering measurements will provide measurements of the liquid fraction, of the bubble structure and dynamics of the material during coarsening. The rational for the systematic measurement vs. foam age is not just to observe and quantify coarsening, but perhaps, to obtain a reproducible self-similar distribution of bubble size. The stability of foams will also be studied in parabolic flight campaigns, giving precursor or complementary results. The rheology of foam will be studied in a future project, using the results and technological developments of “FOAM coarsening” and “FOAM stability projects.
The FOAM coarsening experiment is planned to be integrated in an Experiment Container to be operated in the Fluid Science Laboratory.

- *Justification for the need of space experiment*

Gravity plays an important role in the formation of foam and its subsequent evolution. Its primary effect is to cause excess liquid to drain rapidly away. When the foam is stable enough, it becomes dry and the gravitational force is balanced by a vertical pressure gradient in the liquid (and hence a vertical profile of liquid fraction).

The same difficulty occurs with rheology, in which case a very interesting transition occurs at φ_c where the foam changes from solid-like (finite shear modulus) to liquid-like (disconnected bubbles). This is the "jamming transition" also encountered in other assemblies of randomly packed objects, such as emulsions, sand, clays, etc. In the case of foams, the 20%-35% range, which extends to the wet foam limit at which individual bubbles separate, remains inaccessible on earth. This restricts ground experiments to stable dry foams, and indeed the idealized theoretical models are largely confined to the dry foam limit. The present trend of the subject is therefore towards wet foams as well as dynamic effects.

A micro- or zero-gravity study of wet foam hydrodynamics enables one to overcome the limits imposed by various instabilities experienced under normal gravity. This broader experimental characterization and corresponding insight will provide a scientifically valid alternative for the necessarily conservative empiricism currently employed to estimate the operational window and design for foam handling in industrial processes (such as gas/liquid contacting, flotation and pumping).

- *Experiment specific goals and detailed objectives*

The role of gravity on quiescent wet foams can be captured in the 2 key questions:

1. Is the growth law for average bubble size R~Sqrt[time], such that R dR/dt is a constant? If so, what is the liquid-fraction dependence of this rate?
2. How do the rate and the nature of the bubble rearrangement dynamics change as the liquid fraction is increased to the point of un-jamming?

Both questions require prolonged microgravity to capture the dramatic changes expected for the very wet foams. Answers to both represent baseline knowledge of structure/dynamics upon which flow and rheology must be interpreted. While this program can be usefully carried out for a single surfactant, it is also very interesting to examine different types of surfactants and different additives such as polymers and particulates.

- *Previous flight experiments (precursors)*

• April 2003: 34th ESA parabolic flight campaign, (A. Saint-Jalmes/EADS)
• October 2003: 35th ESA parabolic flight campaign, (A. Saint-Jalmes/EADS)
• June 2004 37th ESA parabolic flight campaign, (S. Marze, A. Saint-Jalmes)
• November 2004 Maxus 6 rocket campaign, (S. Marze, A. Saint-Jalmes, O. Pitois) and (M.Adler, D.Langevin)
• March 2005 41st CNES parabolic flight campaign, (S. Marze, H. Ritacco, A. Saint-Jalmes + 6 students from "Ecole Polytechnique")

- *Reference documents*

AO-99-108 : Hydrodynamics of Wet Foams, Phase III, coordinated by D. Langevin, with D. Weaire, N. Vandewalle, M. Adler.
AO-99-075 : Development of Advanced Foams in Microgravity, Phase III, coordinated by J. Banhart, with B. Kronberg, D. Langevin, S. Odenbach, D.Weaire.

- *Publications*

“Aqueous foam experiments in the MAXUS 6 sounding rocket : towards the development of an ISS module”
A. Saint-Jalmes, S. Marze, D. Langevin, S. Cox, D. Weaire. Proceedings of the 17th European ESA conference on rockets. ESA SP-590. (2005). p.573-578

“The Physics of foams : the module FOAM 2 and its flight on Maxus 6”
Y. Houltz, C.Lockowandt ,P. Andersson, O. Janson, D. Langevin, A. Saint-Jalmes, S. Marze , M. Adler, O. Pitois, B. Kronberg, M. Andersson. Proceedings of the 17th ESA Symposium on European Rocket Sandefjord, Norway, ESA SP-590 (2005) p.565-572

“Electrical conductivity of suspensions : from dry foams to dilute suspensions”,
K. Feitosa, S. Marze, A. Saint-Jalmes, D.J. Durian. *J. Phys.: Condens. Matter* **17** (2005) 6301-6305.

"Foam experiments in parabolic flights : development of an ISS facility and capillary drainage experiments "
A. Saint-Jalmes, M. Safouane, S. Marze, D. Langevin, *Microgravity Sci. Technol.,* **18 -1** (2006) 22-30.

"Experiments and simulations of liquid imbibition in aqueous foams under microgravity”
A. Saint-Jalmes, S.J. Cox, S. Marze, M. Safouane, D.Langevin, D. Weaire,*Microgravity Sci. Technol.* , **18-3/4**, 108-112 (2006).

“Physical chemistry in foam drainage and coarsening”
A. Saint-Jalmes, *Soft Matter*, **2**, 836 (2006)

“Diffusive liquid transport in porous and elastic materials : the case of foams in microgravity”
A. Saint-Jalmes, S. Marze, H. Ritacco, D. Langevin, S. Bail, J. Dubail, G. Roux , L. Guingot, L. Tosini, P. Sung *Phys. Rev. Lett.* **98**, 058303 (2007).

“Rigidity percolation in particle laden foams “
Sylvie Cohen-Addad, Marcel Krzan, Reinhard Höhler, and Benjamin Herzhaft, Accepted by *Phys. Rev. Lett* 2007

Concept diagram:

Experiment cells: a set of cells with fixed contents, or cells with variable contents via injection, or a combination of both. Below a sketch of how these cells could be located inside an FSL Experiment Container (EC).

Diagnostics: - Overview video,
- Conductimetry
- Multiple light scattering spectroscopies (SVS and DWS)

Protocol: Two stages: first, the foam is made at the time T0. The second stage is the study of foam aging: optical diagnostics measure the foam dynamics during aging (up to 24 hours foam age).
Then the cell is replaced by another one or the composition changes (liquid fraction, concentration)

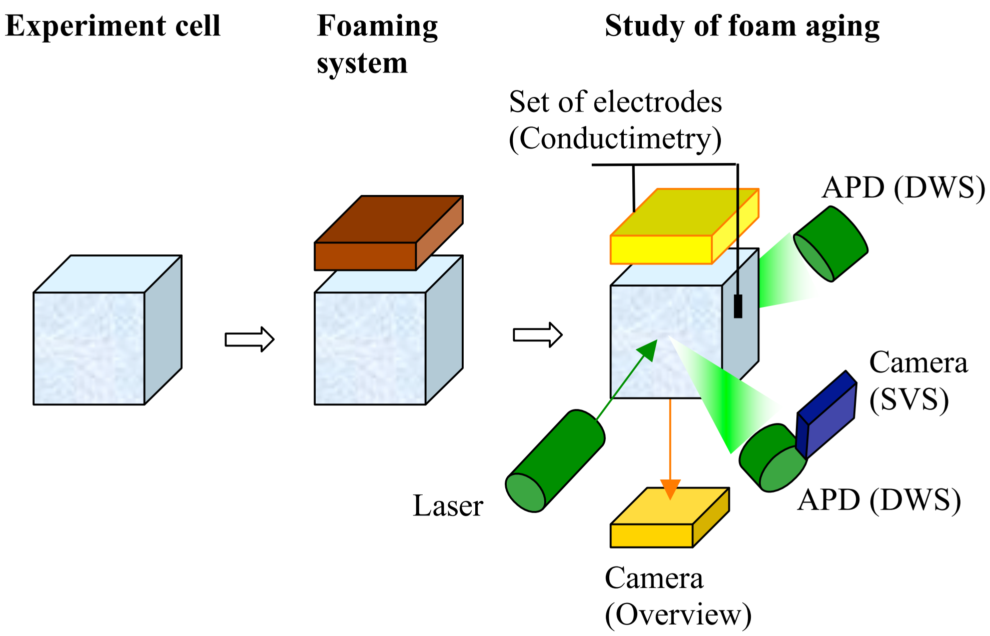


Figure 1: Schematic experimental set-up.

3 SCIENTIFIC REQUIREMENTS ON THE HARDWARE

3.1 Introduction:

Each requirement has been prioritised as minimal or optimal or nice to have. Minimal requirements are those needed to obtain a first scientifically relevant result. Optimal requirements ensure high scientific impact of the results. Nice to have requirements help to exploit fully the experimental possibilities under microgravity conditions to obtain the largest possible scientific output.

Symbol/acronym	Unit	Denomination
ϕ_{liq}		Fraction of liquid in the foam
θ		Incident angle of the laser
l*		Photon mean free path
$g(\tau)$		Light intensity correlation function at delay times τ

Table 1 List of parameters

	Definition
Coarsening	Growth of the average bubble size in a foam due to gas diffusion through the liquid films.
Sample	Foam filling the cell, for a given liquid composition and ϕ_{liq}
Aging	Change of foam structure and dynamics with time

Table 2 Basic scientific definitions

3.2 General requirements

3.2.1. Geometry of the experimental cell

Requirement: The manufacturer is free to choose the geometry of the cell as long as it is compatible with the requirements on foam properties and diagnostics specified below.
The shape of the cell may be adapted to the foaming method chosen which could be either ex situ like the one tested on Maxus 6, or in situ (piston moving back and forth in the cell on both sides of a grid or porous material (not optimal)). In any case, the shape should be such that there are no zones where the foam would not flow, such as corners. A cylindrical cell shape is considered acceptable. In this case, microscopy observation might be supported by rotating the cell in front of the camera. However it is stressed that a completely cylindrical shape could make the interpretation of the optical measurements awkward. A square cross-section with rounded edges would be optimal (see below discussions on the application of optical diagnostics).

The cell volume should be:

- 1 cm^3 minimum (1x1x1 cm^3) minimum for discrete cells with in situ foam production.
- 4 cm^3 optimal (1x2x2 cm^3) for discrete cells with in situ foam production and the possibility to inject liquid or gas to vary liquid fraction, or ex situ foam production.
- 25 cm^3 nice to have (1x5x5 cm^3) but implying either ex situ foam production or a very limited number of discrete cells (1 to 3) to study the different foams and conditions, with a cleaning process between the different foams.

Requirements related to optical diagnostics:
The cell surface should be compatible with the microscopy observation of
- 10 by 10 bubbles all along the coarsening experiment: minimum.
- 25 by 25 bubbles all along the coarsening experiment: optimum.

Translation system to see more bubbles: nice to have.
At any time clear visibility of the Plateau borders is required.
The sample thickness available for diffuse light transmission experiments should be at least 100 times the initial bubble size, if the light transmission DWS diagnostic is implemented.

Antireflective coating on the outer surface would be optimal. No internal coating to control the wetting angle is required.

3.2.2. Materials

Requirement:
The cell material shall respect the following characteristics:
- It should not pollute the solution over a time scale of 6 months. Foaming tests of all solutions to be performed by the scientists at monthly intervals, documented and reported to the project scientist)
- It should be transparent for light in the range of wavelengths of the laser and the backlight.

Comments: Glass and polycarbonate are considered to be good candidates.
Plexiglas is not recommended

3.2.3. Fluid management

Requirement: No specific requirements for the handling and storage of liquid from the filling of the cell to the performance of the experiment in orbit as long as the stability of the liquids is not jeopardised.
The cells should be cleaned before the filling according to the procedure defined by the scientists.
For particle laden foam a stirring system to disperse the particles homogeneously in the foaming solution before foam production should be implemented.
Comments: liquids are defined in paragraph 3.1.5

3.2.4. *Environment control of the EC*

Requirement: Temperature: between 20 and 30ºC. µg level: TBD, – Microgravity requirements: µg level should be known along the experiment: Frequency Range > 1 HZ Resolution of < 5 x 10-8 g. (mandatory). MVIS could be activated to provide an assessment of the sensitivity of foam coarsening to vibrations (nice to have). Avoid UV exposure during storage

3.2.5. *Liquids and particles*

Requirement:
List of liquid:
Comment : for the chemicals listed below, only 1 concentration is foreseen.
Here are given the ranges in which the concentrations can be selected.

	Comment	Minimum concentration	Maximum concentration
Pure water	MilliPore		
Dodecanol	www.sigmaaldrich.com/catalog/search/ProductDetail/FLUKA/44100	1% of the total surfactant mass	3% of the total surfactant mass
Glycerol	www.sigmaaldrich.com/catalog/search/ProductDetail/SIAL/G9012	20%	50%
SDS (anionic surfactant)	www.sigmaaldrich.com/catalog/search/ProductDetail/SIAL/L6026 (Sodium dodecyl sulphate)	4.6g/L =2*cmc (critical micellar concentration) and cmc = 2.3g/L	11.5g/L =5*cmc.
Amilite GCK-12 (anionic surfactant)	www.ajichem.com/DocsProducts/amilite.asp (Pottasium N-cocoyl glycinate)	5g/L	10g/L
Spherical glass beads Averag diameter=60 µm	From Verre industries, ref 45-90 (Croissy Beaubourg - 77313 MARNE LA VALLEE. http://www.verreindustrie.com/	0% Volume fraction	30% Volume fraction

Liquid fraction ϕ_{liq} should cover the range: 5% - 50%, with 10 steps minimum, accuracy: 0.5%.

Particles: Typical liquid fraction in foam = 30%, 36% and typical particle volume fraction in foam = 0%, 15%, 30%, TBC after ground (and ideally parabolic flight) tests of the cell.

Solution: The SDS and dodecanol will be mixed together. SDS will indeed degrade (giving dodecanol), but we will use excess of dodecanol inside of the cells containing SDS, in order to guarantee SDS stability and to be always in the rigid film condition.
The actual amounts of liquid will depend on the cell design.
All solutions have to be verified by the scientists to be stable for at least 6 months (foam must still foam after 6 months of storage of the liquid in the cell; foaming tests of all solutions to be performed by the scientists at monthly intervals, documented and reported to the project scientist).

Comment: For further information about the solution please contact Gille Delon and about particles Sylvie Cohen-Addad or Olivier Pitois.

3.2.6. Gases

Requirement: In all cases the foams should be formed with nitrogen gas, be it by an in situ or ex situ foaming process.
The maximum percentage of gas impurity is 100 ppm, during the experiment(this gas purity is available commercially).

Comments: the FSL experiment container will also be filled with nitrogen gas (around 1 bar). This opens up the possibility of varying the liquid fraction by introducing nitrogen from the experiment container into the cell.

3.3 Performance and functional requirements

3.3.1. Foam generation system

Requirement: The foam generation system shall be able to produce wet foam with the following specifications:

Average bubble diameter: < 100 µm (minimum)
<50 µm (optimum)
Smaller (nice to have)
Bubble size distribution: polydisperse such that standard deviation lies within range 0.3-3 times the average bubble size. No bubbles larger than 5 times the average bubble diameter.

Liquid fraction should cover the range: 5%<ϕ_{liq} <50% 10 different values to be determined in the future (more points close to the wet limit). Accuracy: 0.5%.

Particle laden foam:
Typical liquid fraction in foam = 30%, 36%
Typical particle volume fraction in foam = 0%, 15%, 30%, TBC after ground (and ideally parabolic flight) tests of the cell.

Homogeneity of the average bubble size, liquid fraction, particle fraction: uniform to better than 2% across entire sample.

The bubble size uniformity should be evaluated by taking pictures of all accessible parts of the sample surface. On these pictures, regions containing at least 100 bubbles should be chosen and the average and standard deviation should be calculated. The differences in averages obtained for different pictures should not be much larger than the standard deviation.
Once the bubble size distribution has been verified, the liquid fraction homogeneity can be checked by measuring the variation of the diffuse light transmission intensity across the field of view, as discussed below.

Comments: The closed loop system designed for the breadboards tests performed during the FOAM phase ΔB could be a good candidate inasmuch as it fulfils the above requirements. The non-visibility of the foam loop requires however the presence of a conductivity diagnostics in the cell so as to measure the liquid fraction of the foam.
In contrast, an in-situ generation system would leave no ambiguity on the liquid fraction of the starting foam. This design is currently being designed and will be checked by the scientists in the next parabolic flight campaign.

3.3.2. Foam injection system

Requirement: The manufacturer is free to handle the foam injection in the cell provided that the requirements in 3.2.1 are fulfilled.
The change of the liquid fraction may be by way of direct injection in the cell. The injected liquid will propagate into the originally dryer foam, modifying its liquid content, due to capillary forces. For each liquid fraction several consecutive foaming and coarsening runs will be performed. Alternatively, a progressive reduction of the liquid fraction can also be achieved by injecting gas (nitrogen of the EC ambient) into the cell and homogenizing the foam.
Comment: a global overview of the entire foaming system together with the cell with the large field of view observation would be considered an asset. (nice to have).

3.3.3. Cleaning

Requirement: Unless liquids of different composition are to be used in the same cell, cleaning in space is not required. Otherwise the cleaning procedure should be specified and assessed by the scientists.

Before the cell filling, the cells must be cleaned according to the procedure defined by the scientists.

3.3.4. *Cell leak*

Requirement: The leak of liquid going out the cell should not exceed 1 %TBC of the liquid fraction between the sample cell filling and the end of the experiment process.

3.4 Diagnostics requirements

3.4.1. *Pressure requirements and measurements*

Requirement: The **foam pressure** should be stable when the diagnostics are active. Pressure stability +/- 0.01 bar TBC. No pressure measurement is required.

3.4.2. *Temperature requirements and measurements of the experiment*

Requirement: The **foam temperature** shall be:
- Temperature: between 20°C and 35°C,
- Temperature stability: ± 1 °C for each sample at all liquid fractions.
- Temperature gradient across the experiment cell < 1°C

The foam temperature measurements shall be:
- Measurement accuracy: 0.1°C
- Measurement rate: 1Hz to 0.01Kz TBC
- Number of temperature points: 1 sensor
- Location of thermal sensors: sensor in good thermal contact with the cell

3.4.3. *Conductimetry requirements*

Requirement: Conductance measurements can be performed on the foam with electrodes implemented on both sides of the 1 cm thick cell. These measurements shall provide information on:
- Liquid volume fraction (wetness) of the foam, in that case 1 set of electrodes can be used.
- Distribution and evolution (map) of liquid volume fraction in the cell (nice to have): in that case, 2 sets of electrodes can be used; the electrodes of each set are placed at opposite positions in the cell.

If discrete and sealed cells are used: there is no need to add conductimetry.

If discrete cells are used, but with modifications of the liquid or gas content, a diagnostic for measuring the liquid fraction must be added: it can be conductimetry or it could also be an accurate measurement of the liquid or gas added volume (from the recording of the motion of a piston, for instance).

This measurement is only sensitive to the actual liquid fraction, so it can be coupled to light scattering measurements (which are sensitive to both ϕ and bubble diameter D), to yield separate values for these ϕ and D.

Relations to determine the liquid fraction ϕ_l from the conductances (σ_{foam} is the foam conductance and $\sigma_{solution}$ is the solution conductance).

Relative conductance: $\boxed{\sigma = \frac{\sigma_{foam}}{\sigma_{solution}}}$ And $\boxed{\Phi_l = \frac{3\sigma(1+11\sigma)}{1+25\sigma+10\sigma^2}}$

Reference : *"electrical conductivity of dispersions : from dry foams to dilute suspensions" K. Feitosa, S. Marze, A. St-Jalmes, DJ. Durian, J. Phys.: Condens Matter 17 (2005) 6304*

The electrode pairs must be on top of each other.

Measurement rate:
Optimal: 1 measure / s during the whole coarsening experiment.
Minimal: 1 measure / min

Conductivity to be measured:
Range: from 1 to 200 µSiemens.
Accuracy: up to 5 µSiemens.

Requirements on contacts:
The electrodes default position is preferably inside the FOV of the overview camera. This approach enables a correlation with the CCD images, but can make the DTS computations from the CCD overview images less easy.
The electrodes shall not protrude but shall be flush with the plate they are inserted in.
Foam contact surface area: minimised, 1 mm^2 typically.

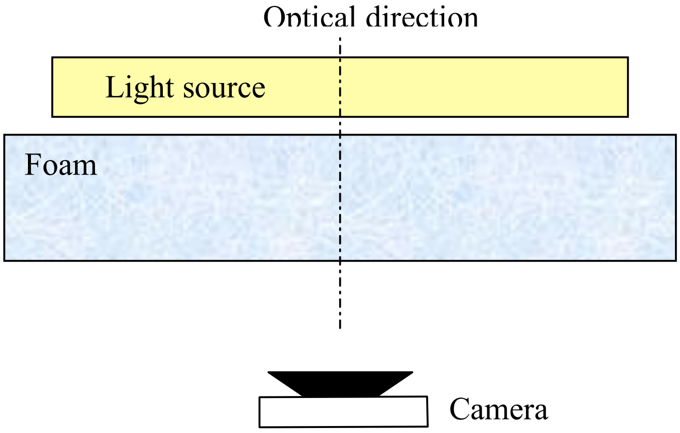
Transparency: The electrodes are not required to be transparent, but their implementation has to minimise the areas of no transparency.
Voltage required:
- Value: between 1 to 10 Volt
- Frequency: 1 kHz
- Accuracy: .01 Volt
- Stability in time : 0.01 Volt/hr

Comment: For other information about this requirement, Arnaud Saint-Jalmes can be contacted.

3.4.4. Overview CCD

Requirement:
The overview camera will be used just before and after the DWS/SVS diagnostics: It has 2 modes of operation: Still mode or Video mode.
The Still mode is a minimal requirement in all cases.
The Video mode is a minimal requirement only if SVS or DWS measurements cannot be performed. Otherwise the video mode is an optimum requirement.

OVERVIEW CCD – STILL MODE
Purposes: (1-minimal) To inspect uniformity of foam production; (2-minimal) to determine average bubble size; (3-minimal) to determine width of bubble size distribution; (4-optimal) to determine bubble size distribution. Here "bubble size" means a typical diameter of the cross-sectional area of bubbles at the surface of the sample cell within the field of view.



Imaging Requirements:
Depth of Focus (DOF): 100 µm from the wall (no more than one bubble.)
Field of View (FOV): as far as possible the full cell.
To resolve the areas of all bubbles, the FOV must encompass at least 10x10 average bubbles (25x25 is optimal). Resolution must be at least 512x512 pixels (2048x2048 is optimal). In practice, this means a FOV with zoom from 0.5*0.5 mm2 to 1.5*1.5 mm2 +/- 10% if the average bubbles size grows by a factor 3 (from 50µm to 150µm).TBC
Since the overview camera should allow to check foam homogeneity, the maximum FOV should be equal to the cell size.
The bubble size grows during the experiment, so zoom capability is necessary. This could be accomplished either continuously (eg zoom lens) or in discrete steps (eg different objective). Since the bubble size obtained in space cannot be easily predicted in all cases, changing the zoom by remote control would be necessary for optimal operation of the experiment.

Illumination Requirement: The illumination at the CCD must be uniform to better than 10% across the entire field of view (1% is optimal), in the absence of foam

(empty cell). Moreover, when foam is replaced by a non absorbing homogeneous liquid which has the same diffuse light transmission properties, the FOV seen by the overview camera should also have a light intensity homogeneous within +-10%. The scientists will provide latex suspensions in water for this test (1) (2).
Satisfying the latter requirement may require reflective coatings of the lateral sample boundaries. The intensity of the light source shall be demonstrated to be stable within 1 % over one run TBC or shall be monitored during operations. (3). In the latter case, light backscattered from the foam sample must not contribute more than 2% to the measured signal.

Image frame rate: for the first hour: every 3min, from then on every 10 min
Acquisition time along 1 run: 10 msec

Radiometry:
Foams coarsen and as a function of time, the light intensity transmitted will vary by more than a factor of 100. The average transmission loss of foam is up to 50% TBC.

OVERVIEW CCD – VIDEO MODE

Purpose: to image the evolution of the foam structure (bubble rearrangement dynamics). This diagnostic is optimum only if the DWS/DTS and SVS are implemented. Otherwise the Video Mode is minimal.

Illumination, radiometry and imaging requirements as per “still mode”.

Image frame rate: 100 Hz (10 times the inverse of a typical rearrangements duration)
Acquisition time along 1 run: (long enough to observe 100 events. Exact values will depend upon liquid fraction and field of view, and will change as the foam evolves.) Minimum: 100s starting at a foam age of 5minutes for each run. Optimum: in addition 100s at a foam age of 500 minutes, with a frame rate of 30 Hz.

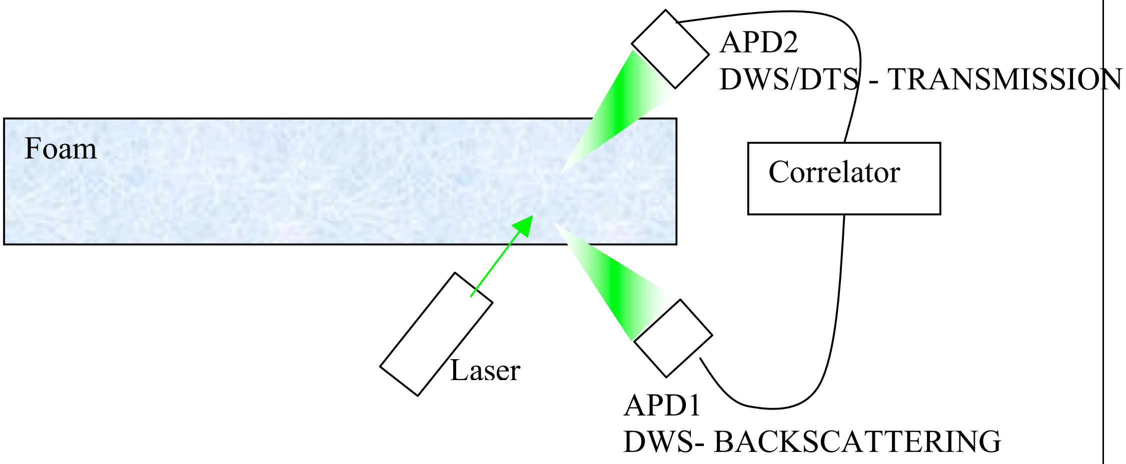
Without any data compression, a 100s acquisition would typically produce of the order of 10GB of data. However, for intermittent evolution such as bubble rearrangements dynamic video compression such as MPEG4 of DIVX should dramatically reduce the data storage requirement.

Telemetry requirements (minimal): It should be possible to adjust the acquisition time, frame rate, illumination intensity and camera, after 1 run.
Comments:
(1) Illumination may be accomplished by transmission across the sample or though the faces away from the viewing region; experience shows poor contrast is obtained by direct illumination of viewing region.
(2) LED source is adequate.
(3) To achieve homogeneous illumination with minimal LED intensity and space requirements, commercially available technologies such as those presented in http://www.glthome.com/tech.htm could be useful.

Comment: For other information about this requirement, Douglas Durian or Arnaud Saint–Jalmes or Reinhard Höhler can be contacted.

3.4.5. Light scattering measurements: DWS

Requirements:
The Diffusing Wave Spectroscopy (DWS) technique is divided in 2 diagnostics: DWS Backscattering and DWS/DTS- Transmission. The DWS/DTS requirements are classified as “optimal”. However, if SVS requirements cannot be met then DWS-Backscattering requirements are “minimal” and DWS/DTS requirements are “minimal”.



DWS - BACKSCATTERING

Purpose: To characterize the nature and average rate of bubble rearrangement dynamics through measurement of the time-averaged intensity autocorrelation function <I(0)I(t)>/<I^2> vs. t for backscattered light.

General requirements: As per standard practice, the overriding concerns are that the path-length distribution for detected photons be known, that the intensity be high enough and the collection time be long enough for good statistics, and that the light be coherent. This diagnostic need not be performed simultaneously with any other.

Laser:
Uniform illumination over an area of at least 10x10 bubbles; illumination area could be up to area of sample face. In practice, this means an illumination area of at least 1.5*1.5 mm^2 +/- 40%. The area of illumination must be fixed.

Incidence angle may be inclined no more than θ=15 degrees away from normal. Coherence length must be four times longer than the width of the photon path length distribution: 50 cm is minimal and 2 m is optimal.
Intensity must be such that the count rate of the photo detector is larger than 100kHz, but it must not saturate the detector/correlator system or heat the sample. It must be possible to monitor and adjust the laser intensity via telemetry.
Stability must be no worse than 1% over ten minutes.
Wavelength must be in the visible, eg 532 nm from NdYAG. The only requirement on polarization state is that it be constant.

Detector System:
Must collect photons only from a well-specified region which subtends no fewer than thirty bubbles and over which the intensity is constant; eg at centre of illumination area by use of GRIN lens. A mono-mode optical fibre must be used. Between the fibre and the detector, there should be a linear polarization filter. The detector (eg avalanche photo-diode) must count individual photons and send a corresponding train of logic pulses to a digital Correlator.

Other lights sources: Cross-talk from other light sources and dark counts must sum to less than 100 Hz. This means that no light from the environment in the space station should penetrate into the experimental device. The requirement can be checked on ground by recording the photon counts in the device in an environment where the ambient light intensity is comparable to that in the space station.

Digital Correlator:
Must collect logic pulses and compute the intensity autocorrelation function $<I(0)I(t)>$ as well as the average intensity $<I>$. The sequence of delay times t must span the range of decay of $<I(0)I(t)>$ from $<I^2>$ at short t to $<I>^2$ at long t; eg by use of commercial digital correlator with logarithmic spacing from 10 ns to 100 s (such as those produced by the company correlator.com, see http://www.correlator.com/). The correlator should have 2 channels so that transmission and backscattering can be monitored simultaneously.

Acquisition time: 100 s for a single acquisition for freshly formed foam, going up to 300s at the end of the experiment. At least 20 such acquisitions are needed for a given sample during the coarsening process.

DWS/DTS - TRANSMISSION

Purpose: As for DWS in backscattering, the purpose is to characterize the nature and average rate of bubble rearrangement dynamics though measurement of the time-averaged intensity autocorrelation function $<I(0)I(t)>/<I^2>$. Use of transmission will (1) test whether or not bulk behaviour is identical to the near-surface behaviour probed by DWS-backscattering and by SVS, and (2) will also give complementary information on the transport mean-free path l* via measurement of the average intensity $<I>$. The latter is referred to as DTS.

Requirements: The illumination, detection, and processing requirements are identical to those for DWS-backscattering, but are more difficult to satisfy for several reasons: fewer photons are transmitted, so the intensity must be greater and the coherence length must be longer;,
As a rule of thumb, the diffuse light transmission coefficient scales as l* divided by the sample thickness and for the wettest foams, l* is comparable to the bubble size.

Acquisition time: Should be simultaneous with the backscattering measurement. 100 s for a single acquisition for freshly formed foam, going up to 300s at the end of the experiment. At least 20 such acquisitions are needed for a given sample during the coarsening process.

Data storage: The typical amount of data is below 100kb for a run of 12 hours..

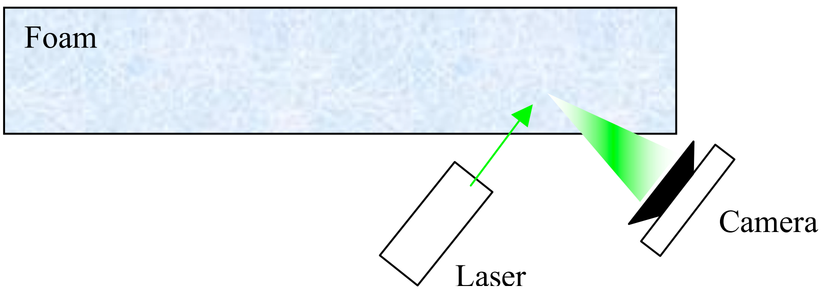
Telemetry requirements: It should be possible to adjust the acquisition time, laser intensity and detector system, after 1 run.

References on DWS and photon diffusion in foams:
D. J. Durian, D. A. Weitz, and D. J. Pine, "Multiple Light-Scattering Probes of Foam Structure and Dynamics", Science 252, 686-8 (1991).
D. J. Durian, D. A. Weitz, and D. J. Pine, "Scaling Behavior in Shaving Cream", Physical Review A 44, R7902-R5 (1991).

Comment: For other information about this requirement, please contact Reinhard Höhler or Douglas Durian.

3.4.6. Light scattering measurements: SVS

Requirement: SPECKLE-VISIBILITY SPECTROSCOPY (SVS)



Purpose:
This technique is a multi-speckle time-resolved version of DWS. It is to be used to characterize the duration of rearrangement events, and the speed of bubble motion during an event, via measurement of the visibility V(T) of the speckle pattern for a specified exposure duration T vs time t. Specifically, V is the variance of intensity

levels registered by the pixels of a CCD camera. The size of events may also be deduced by variation of illumination/detection spot.

General requirements:
Similar to DWS in that laser must be coherent and that path length distribution be known. (The path length distribution in the sample can be determined by experiments on ground where the sample cell is filled with a well characterized aqueous latex suspension and the light intensity autocorrelation function is recorded. The calculations necessary for analyzing these data will be performed by the scientists).

Laser:
Illumination and detection through circular aperture on face of sample. Diameter of aperture to be varied from 3 to 30 bubbles across. Note that this size varies as the foam ages. Power adjusted so that average grayscale level of the CCD detector is predominantly in range 40-80 out of 255. Using a lens that can be translated along the beam will help to achieve these requirements.

Detector system:
Eight-bit CCS camera (CCS to be defined/detailed) or a linear CCD camera with at least 1024 pixels (8 times more is optimal; 64 times more would be nice).
Camera must be placed such that speckle-size is about half the CCD pixel size. CCD pixel size: not critical as long as it matches with a speckle for the largest illuminated spot size (from the laser beam). The speckle size is roughly given by spot to detector distance times wavelength divided by spot diameter.
Dark counts and cross talk no more than 4 grayscale levels. Exposure duration T: variable in range 20 microseconds to 1 millisecond.
Duration of acquisition: (long enough to capture a least 100 rearrangement events). Minimum of the order of 100s
Number of acquisition per run: minimum of the order of 10.
Frame rate: 100 Hz minimum (1000 Hz nice to have). The frame rate should be at least 10 times larger than the inverse of the characteristic duration of bubble rearrangements.

Processing/storage: Video data need not be stored. Rather, the idea is compute the variance on the fly and record only that number vs time. To avoid normalization and speckle/detector size effects, the specific quantity to be computed is V(2T)/V(T) where the numerator refers to the variance of the sum of two successive images and the denominator refers to the average variance of the two individual images.
SVS acquisition will not be required during DWS experiments or overview CCD.

Telemetry requirements: It should be possible to adjust the acquisition time, laser intensity and detector system, after 1 run.

References on SVS:
[1] R. Bandyopadhyay, A. S. Gittings, S. S. Suh, P. K. Dixon, and D. J. Durian, "Speckle-visibility spectroscopy: A tool to study time-varying dynamics", Review of Scientific Instruments 76, 093110/1-11 (2005).

Comment: For other information about this requirement, Douglas Durian or Reinhard Höhler can be contacted.

4 SCIENTIFIC REQUIREMENTS ON OPERATIONS

Crew: Involvement is required to insert and to install the Experiment Container and start experiment.

Experiment runs are in automatic mode with monitoring from the ground, without crew involvement.

	Definition
Sample	Foam filling the cell, for a given liquid composition and ϕ_{liq}
run	A run is a full experience for one liquid composition

4.1 Experiment protocol

Experiment protocol: For each foam sample, there are different set of measurements that are to be repeated one after the other, for a total duration of 112.5 days. An overall sequence is given in the following table.
Data acquisition (t=0) must start just at the end of the foaming process.

Number of samples:
For coarsening: 5 chemical systems are foreseen (see 3.1.5); for each, 10 different liquid fractions = 40 samples to be measured.
Composition 1: SDS
Composition 2: SDS+dodecanol
Composition 3: SDS+glycerol
Composition 4: GCK
Composition 5: SDS + glass beads

Here are 5 possible compositions: it is still not determined by the scientists which composition is “optional”.
Each sample must be tested at least 2 times (3 is better) (one just needs to re-foam the sample after its first period of coarsening).

Measurements:
Conductimetry and CCD overview are permanently running.
However, during DWS and SVS (requiring laser light), the overview/microscope illumination might need to be shut down (TBD). The number of SVS and DWS acquisition / experiment is TBD.

Duration:
For the low liquid fractions (up to 0.25), experiment duration is 12h; for the high liquid fractions (up to 0.5), experiment duration = 24h.
In the maximum case: 5 chemicals + 10 liquid fractions (5 studied for 12h and 5 studied for 24h) + 3 runs / sample: the experiment duration is:

5*5*12*3 + 5*5*24*3 = 2700 h = 112.5 days.

Foam age (Hrs)	**Measurements**	**Data per run**	**Durations per run (min)**	**comments**
T=0	Homogenous foam in the cell and start data-taking software	0	0	
0- 12 or 24	Conductimetry,	< 1 Mb	1 min	To measure the liquid fraction
	SVS,	< 10 Mb	< 1000 s	To measure the bubble rearrangements. The time slot for SVS and DWS should follow the dynamics of rearrangements, which follow a power law.
	DWS, DTS	< 100 kb	1, 4, 10…TBD	
	Camera	10 Go without compression, probably more than an order of magnitude less with dynamics video compression. Further reduction possible with reduced FOV or resolution	< 1000s	

Table 3 Sequence operation for 1 single run

Exp	**Solution**	ϕ_{liq}	**Concentration**	**Number of runs**	**Duration per run (hour)**	**Data minimal (Mb)**	**Data Optimal (Mb)**
1	1			3	12		
2	1			3	12		
3	1			3	12		
4	1			3	12		
5	1			3	12		
6	1			3	24		
7	1			3	24		
8	1			3	24		
9	1			3	24		
10	1			3	24		
11	2			3	12		

12	2			3	12		
13	2			3	12		
14	2			3	12		
15	2			3	12		
16	2			3	24		
17	2			3	24		
18	2			3	24		
19	2			3	24		
20	2			3	24		
21	3			3	12		
22	3			3	12		
23	3			3	12		
24	3			3	12		
25	3			3	12		
26	3			3	24		
27	3			3	24		
28	3			3	24		
29	3			3	24		
30	3			3	24		
31	4			3	12		
32	4			3	12		
33	4			3	12		
34	4			3	12		
35	4			3	12		
36	4			3	24		
37	4			3	24		
38	4			3	24		
39	4			3	24		
40	4			3	24		
TOTAL				120 runs	2160 h	TBD	TBD

Table 4 Samples compositions

- Parameters measured: *Please list all the parameters (in an exhaustive way) and their respective range, if applicable.*

- Number of test subjects: n/a

Ground reference experiment(s):
Optical experiments to establish the photon path length distribution in the cell as mentioned above.

4.2 Science constraints during operational phases

4.2.1. Transportation requirements (between lab and launch):

Temperature requirements: between 5°C and 40°C

4.2.2. Pre-flight BDC / Operations / Late Access:

Functional tests of the flight model need to be done by the Science team before the launch (mandatory). Purpose: to adjust software and hardware parameters. Duration: at least 5 days (depend on the instrument complexity).
The late access will depend sample life time (given by the manufacturer).

4.2.3. Upload science constraints: N/A

4.2.4. *In-flight science activities:*

c.f. the protocol, section 4.1.

4.2.5. In-flight science constraints:

Microgravity requirements: The µg level should be known along the experiment: Frequency Range > 1 HZ Resolution of < 5 x 10-8 g. (mandatory).
Requirements on time in flight: The expected duration is TBD

4.2.6. Download science constraints (including samples): N/A

4.2.7. Post-flight BDC / Operations / Early Retrieval:

According the very preliminary time line, the duration is about 1 month TBD.
Transportation requirements (between landing and lab): n/a

4.2.8. Possibility to interrupt the experiment:

Interruption between runs can be done without loss of science.
During a run, the experiment should not be interrupted. The loss of science is serious and the run shall be re-started.

4.3 Communications requirements

- Requirements on telemetry / data downlink / storage:

Downlink:
Camera overview: 1 image per 5 seconds for a period of 2 minutes, every 20 minutes.
Video images compression: JPEG allowed, by a factor of TBD maximum.
Storage capability: minimum TBD, optimal TBD and nice to have TBD.

- Requirements on commands uplink: The below parameters of the instrument should be controlled on-ground:
  - Laser intensity
  - Camera shutter speed
  - Foaming system
  - Light system

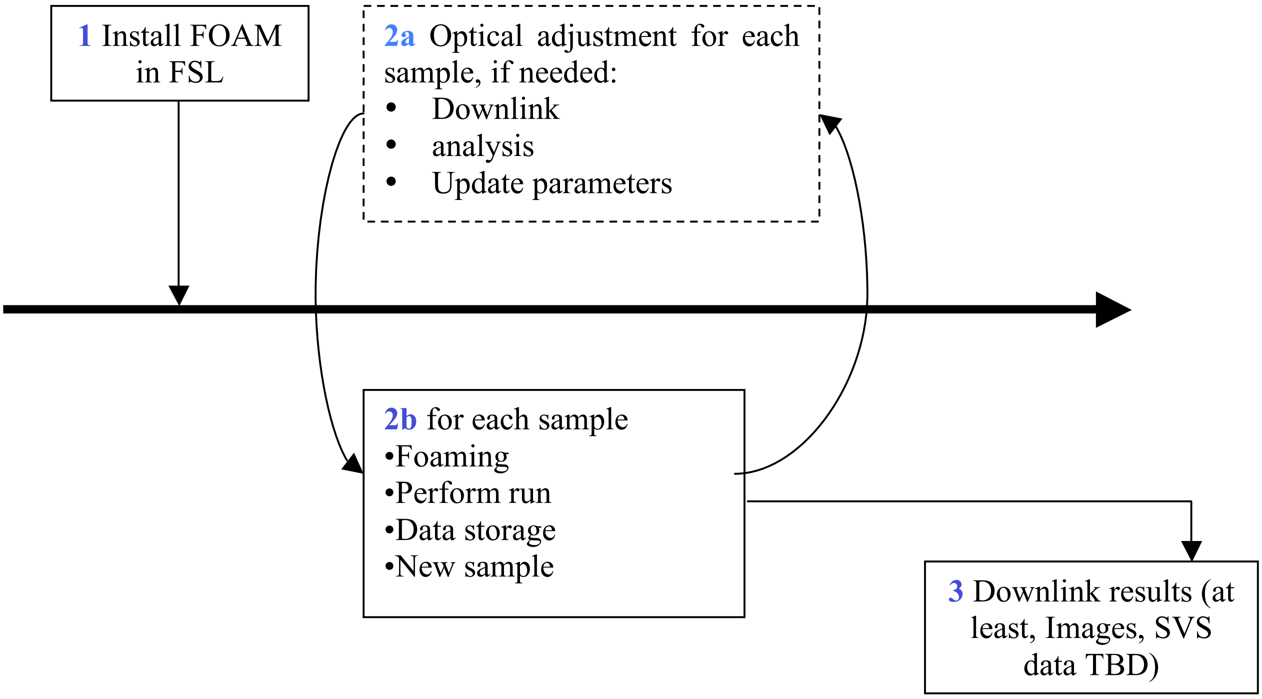
Response time needs to be near-real-time.

- Imagery requirements: *Note: This section refers to taking photos or videos of the experiment setup or conduction for scientific purposes only (not educational, public relations or other purposes).* : N/A

4.4 Detailed Experiment Timeline and associated Functional Objectives

In this Section, please describe graphically the timeline of science events (covering if necessary pre-flight / in-flight / post-flight) for the experiment. Please indicate time flexibility.
(Note: You may generate several timelines for pre- / in- / post-flight science requirements, to ensure clarity of the graphical descriptions)

A **run** is an experiment on 1 sample.
A **sample** is Foam filling the cell, for a given liquid composition and ϕ_{liq}



Functional Objectives description:
Step 1: Install FOAM instrument
Step 2a: Optical adjustment for each sample, if needed:
Step 2b: run on one sample then change the sample or same sample
Step 3: Part of the data should be downlinked
Step 4: End the experiment Uninstall

List of Functional Objectives (FO) related to *pre-flight / in-flight / post-flight* timeline – Refer to Slide *XX*.

FO step number	FO description	Duration (hh:mm)			Resources				
		Min	Preferred	Max	Crew	Response time	Data / Cmd	Data amount Min	Data amount preferred
1	Install instrument				Yes				
2a	Adjustment If needed					Near real time	Yes	TBD	TBD
2b ◄	Run Camera, SVS, DWS and conductimetry Change sample and back to 2a		10 hours per run						
	For all samples to be performed	TBD	TBD	TBD					
3	Downlink results							TBD	TBD
4	Uninstall				Yes				

* *<u>Note:</u> crew activity duration indicated in this column refers to scientific needs only (e.g. blood pressure measurement etc…), NOT to activities related to the practical implementation of the experiment (e.g. samples exchange, tape exchange etc…).*

5 EXPERIMENT OUTPUTS

5.1 Science deliverables

The data stored in flight should be delivered as far as possible to the science team.

5.2 Planned analyses

Appendix 1 - SUMMARY TABLE

Open Issues	Actions	Actionee	Due date
§3.1.4 §3.1.5 long duration tests: solution and material	6 months tests	Science team	
§4.1 solution composition, data storage capacity	TBD	Science team	
§			
§			